AN INVESTIGATION OF THE EFFECT OF BACK PRESSURE UPON THE FLOW OF AIR THROUGH A CENTRIFUGAL FAN.

A Thesis Submitted To
The Faculty Of The Towne Scientific School
Of
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For The
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In
MECHANICAL ENGINEERING
By

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INTRODUCTION.

In the blowing of glass, trouble is often experienced due to the walls of the cylindrical glass bubble expanding unevenly, resulting in bulges or blisters. A certain glass company, who used compressed air for blowing, claimed that this irregularity was caused by a sudden increase of pressure within the hot cylinder, and resorted to the expedient of drilling a small hole in the discharge pipe of the compressed air tank, believing thus to provide a means of relieving this excess pressure, and so prevent the bulging of the glass. The device was thought practical, and patented.

At about the same time, another company, experiencing a similar difficulty in blowing, discarded the use of compressed air and substituted a blower, so that the pressure might be easily varied, and reduced as soon as the glass commenced to expand unevenly. Upon learning of a blower being put to such a purpose, the first company brought suit against the second on the grounds that the excess pressure could pass through the discharge pipe as a back draft and relieve itself at the eye of the fan, and therefore the apparatus acted in the same manner as their relief hole and

was an infringement upon their patent rights.

The matter was subjected to a series of tests, and the conclusion was reached that, under ordinary conditions of use, the blower could not form a means of relieving the pressure to such an extent as to be effective in preventing deformation of the glass.

Tese tests have been taken as the basis for the topic of this thesis; the object has been, first of all, to determine if a back draft actually does occur when the pressure at the point of discharge is suddenly increased, and secondly, to determine the magnitude of this back draft.

DESCRIPTION OF APPARATUS.

The set consisted of a No. 00 Buffalo centrifugal fan belt driven by a 3 HP direct current motor, and discharging through a 4 inch pipe into a sheet metal tank of 20 cubic feet capacity equipped with quick-acting valve at one end, which simulated the cylinder of molten glass of the original problem in providing a large volume of air at the point of discharge. Figure 2 shows the manner in which the apparatus was set up.

The instruments used in the test were; three U-tube water manometers of about 16 inch capacity; an Ellison

inclined draft gauge; and a tachometer and a Veeder speed counter, the latter to measure speeds which were beyond the tachometer. An attempt was also made to a pair of small pendulums to measure back draft by a method which shall be described later, but it was found to be impracticable, and a draft gauge used instead.

CONDUCT OF TEST.

Since the blower had been just purchased, it was first neccessary to determine its normal characteristics - that is, the effect of various speeds of rotation upon its discharge pressure and rate of discharge under rated operating conditions. For this purpose five sets of runs were made, as follows: three runs with the tank disconnected - the first with the end of discharge pipe entirely open, the second with the end of the pipe covered by a tight fitting lid having a 1-inch round hole in its center, and the third with the pipe completely stopped. The other two runs were made with the tank connected, the quick-acting valve being open during one, and closed during the other. In each run the fan was operated at from ten to fifteen different speeds, and the corresponding total and static discharge heads, and the static draft head measured - the former by means of a pitot tube inserted in the discharge pipe some 4 feet from the outlet of the

fan, and the latter with the inclined draft gauge connected to the intake at a point sufficiently far from the entrance to avoid eddy currents. There was considerable difficulty experienced in obtaining consistent results owing to fluctuations in the speed of the motor, and leakage around the joints of the manometers, which were difficult to keep tight because of having to dismantle the apparatus at the end of each day's runs.

When these calibrations were completed, the heart of the experiment was in order - the investigation of back draft. It was here that most difficulty came up; it was soon evident that a puff of air did travel back through the discharge pipe and emerge at the eye of the fan, as a paper streamer placed at the mouth of the intake showad conclusively, but it was of such brief duration and occurred so rapidly that the manometers and draft gauge failed to indicate it. The pendulums were then tried; two oblong pieces of thin wood, about 4 inches in length were suspended on a wire at the mouth of the intake, one of which was free to swing either outward or inward, while the other was stopped so as to be able to swing outward only. By measuring the inward deflection of the free pendulum with a protractor while the tank valve was open, and the outward swing of the stopped pendulum which occurred the moment the valve was

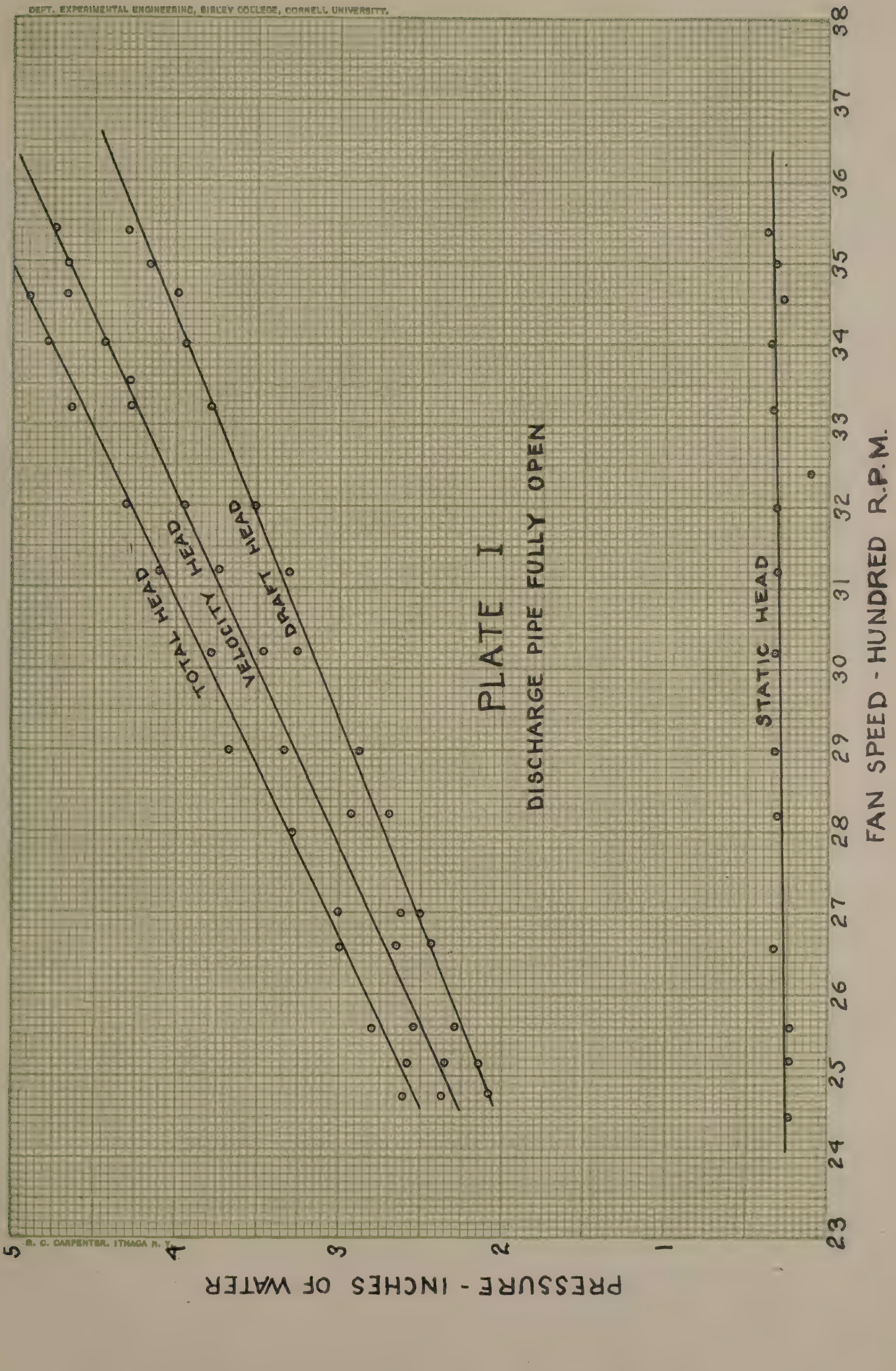
closed, it was intended to calculate the forces acting upon them and hence obtain a comparison between back draft and suction; but it was soon found impossible to measure the deflections of the pendulums with any degree of accuracy, and still further impossible to time the motion of the stopped pendulum, and so the scheme was abandoned. The draft gauge was again resorted to, and by varying its angle of inclination, a position was found in which it was sufficiently sensitive to indicate the puff-back with fair accuracy, and it was decided to use it thus. A run was now made with about the same range of speeds as before, but taking two sets of readings at each speed - one of discharge pressures and draft while the tank valve was open, and then, upon closing the valve suddenly, noting the deflection of the draft gauge. Correction for the change in inclination of the latter has been made by multiplying the actual readings on the scale, which was calibrated in the ratio of $\frac{1}{2}$ inch to the inch, by $\frac{1}{2}$ x sin angle of inclination.

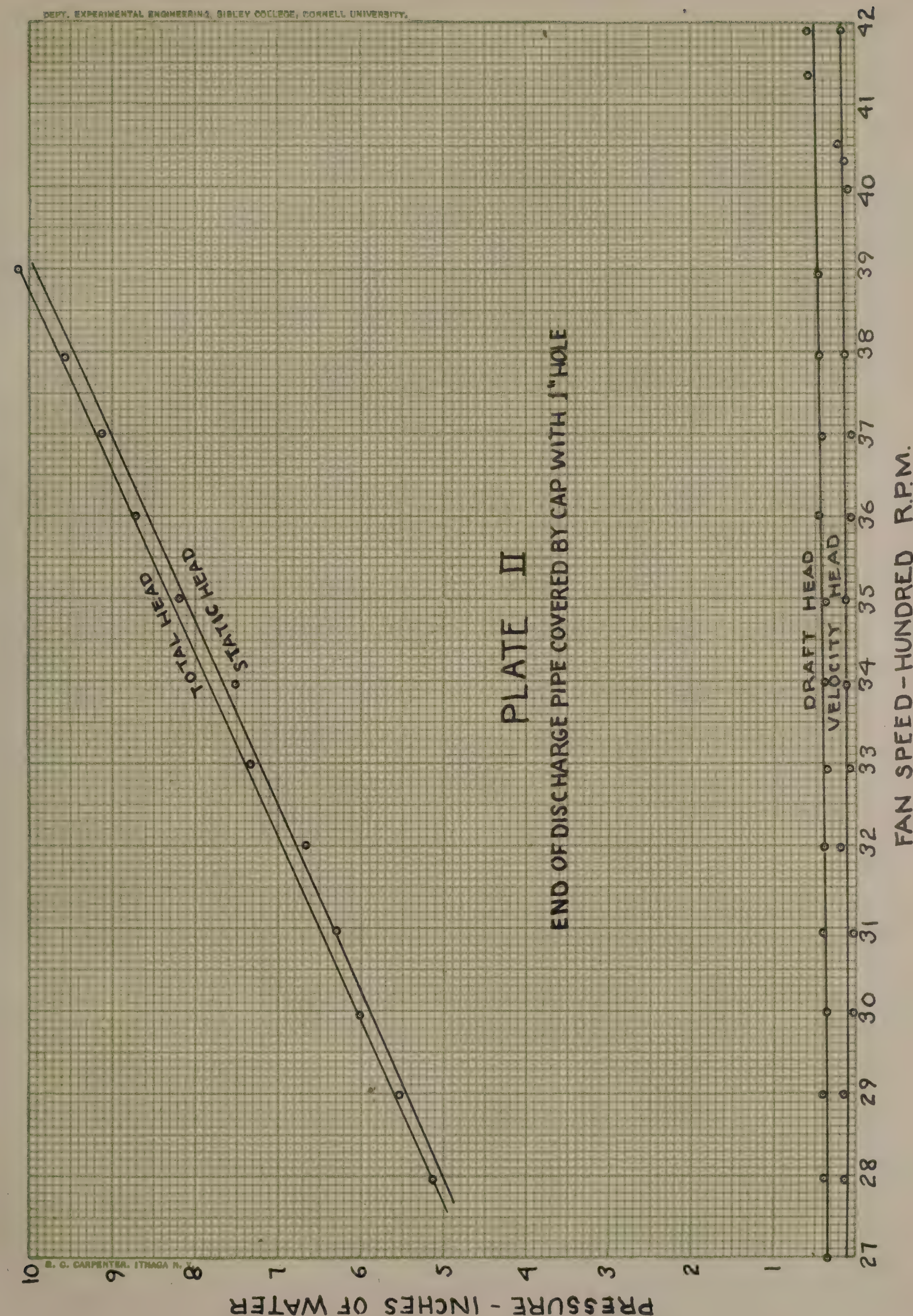
DISCUSSION OF RESULTS.

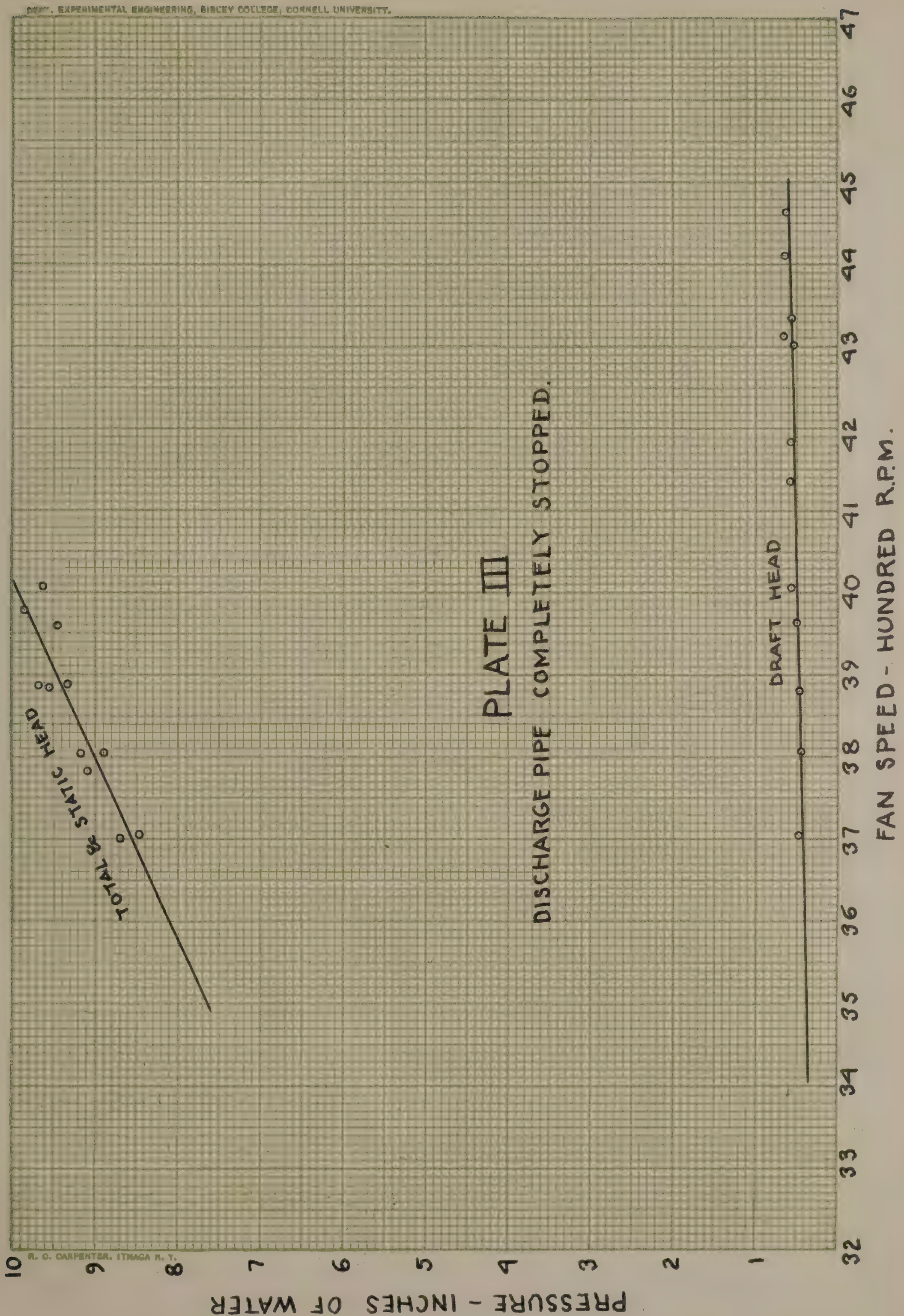
Plates I to IX show the normal characteristics of the blower, and plate X shows the magnitude of the back draft occurring at different speeds. As previously mentioned, there are discrepancies in the results of similar runs made at different times, the extent of these variations being illustrated by the curves of plates XI to XIV; therefore most of the curves on plates IV to IX are plotted the composite data of each set of similar runs.

The back draft, according to X, attains a maximum value of 0.34 inches of water at a fan speed of 4000 R.P.M. and has a duration of, at the most, a second; it seems in fact to be a compression wave rather than an actual puff of air. A mass of air is moving rapidly while the valve of the tank is open, and is stopped suddenly when the valve is thrown shut; the inertia of the mass causes a compression region to form, which is reflected through the system very much in the manner of a sound wave.

In view of these considerations, this back draft could have no significance commercially. It produces no noticeable effect upon the water column of a U-tube manometer, and there is not any likelihood of its altering the pressure within a cylinder of molten glass sufficiently to prevent the formation of bulges.


DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.
PLATE I
DISCHARGE PIPE FULLY OPEN
TOTAL HEAD
VELOCITY HEAD
DRAFT HEAD
STATIC HEAD
FAN SPEED - HUNDRED R.P.M.
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
PRESSURE - INCHES OF WATER
1
2
3
4
5
R. C. CARPENTER, ITHACA N. Y.


DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.
PLATE II
END OF DISCHARGE PIPE COVERED BY CAP WITH 1" HOLE
TOTAL HEAD
STATIC HEAD
DRAFT HEAD
VELOCITY HEAD
27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42
FAN SPEED-HUNDRED R.P.M.
1 2 3 4 5 6 7 8 9 10
PRESSURE - INCHES OF WATER
E. C. CARPENTER, ITHACA N. Y.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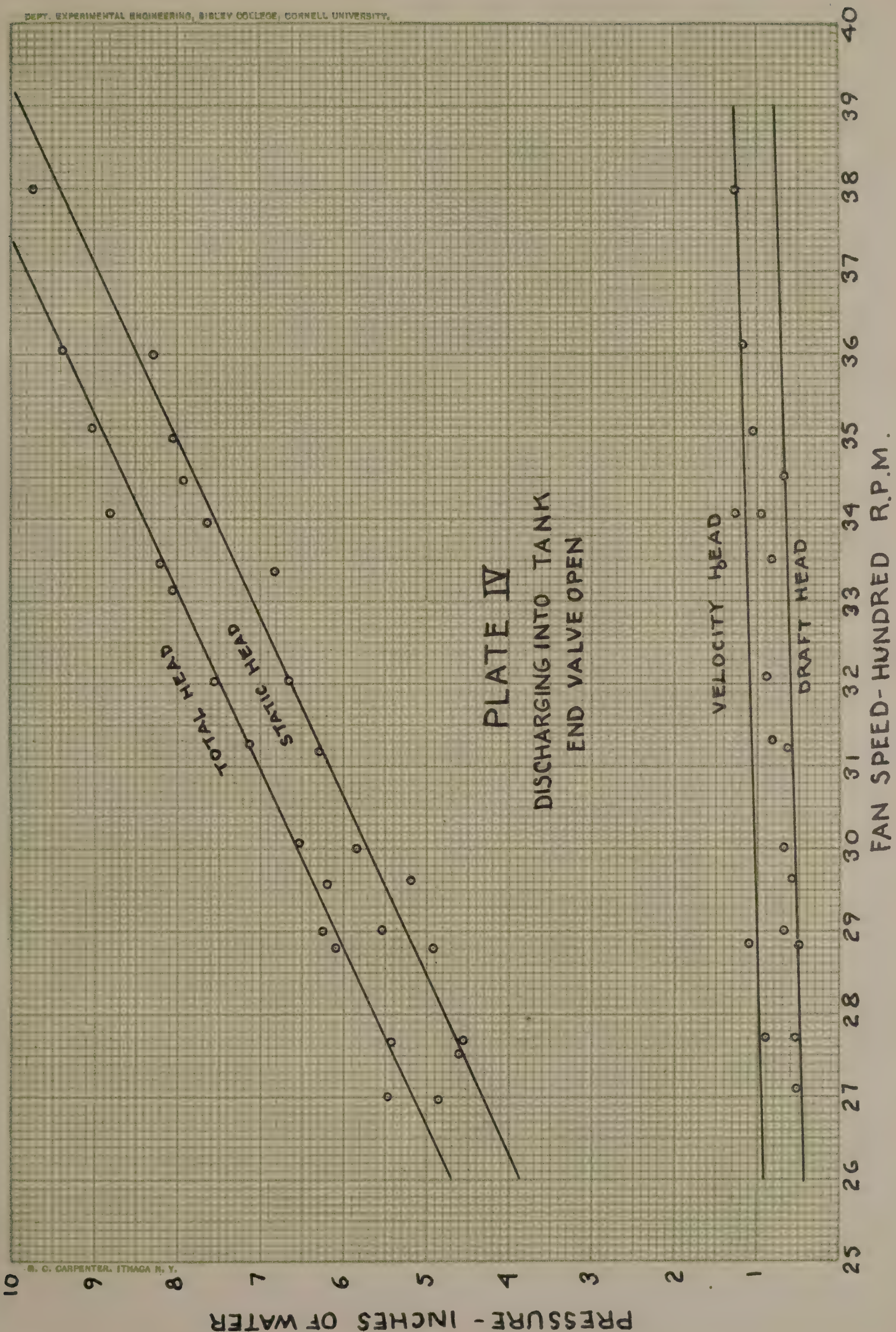
R. C. CARPENTER, ITHACA N. Y.
PLATE III
DISCHARGE PIPE COMPLETELY STOPPED.
TOTAL & STATIC HEAD
DRAFT HEAD
FAN SPEED - HUNDRED R.P.M.
32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47
PRESSURE - INCHES OF WATER
10 9 8 7 6 5 4 3 2 1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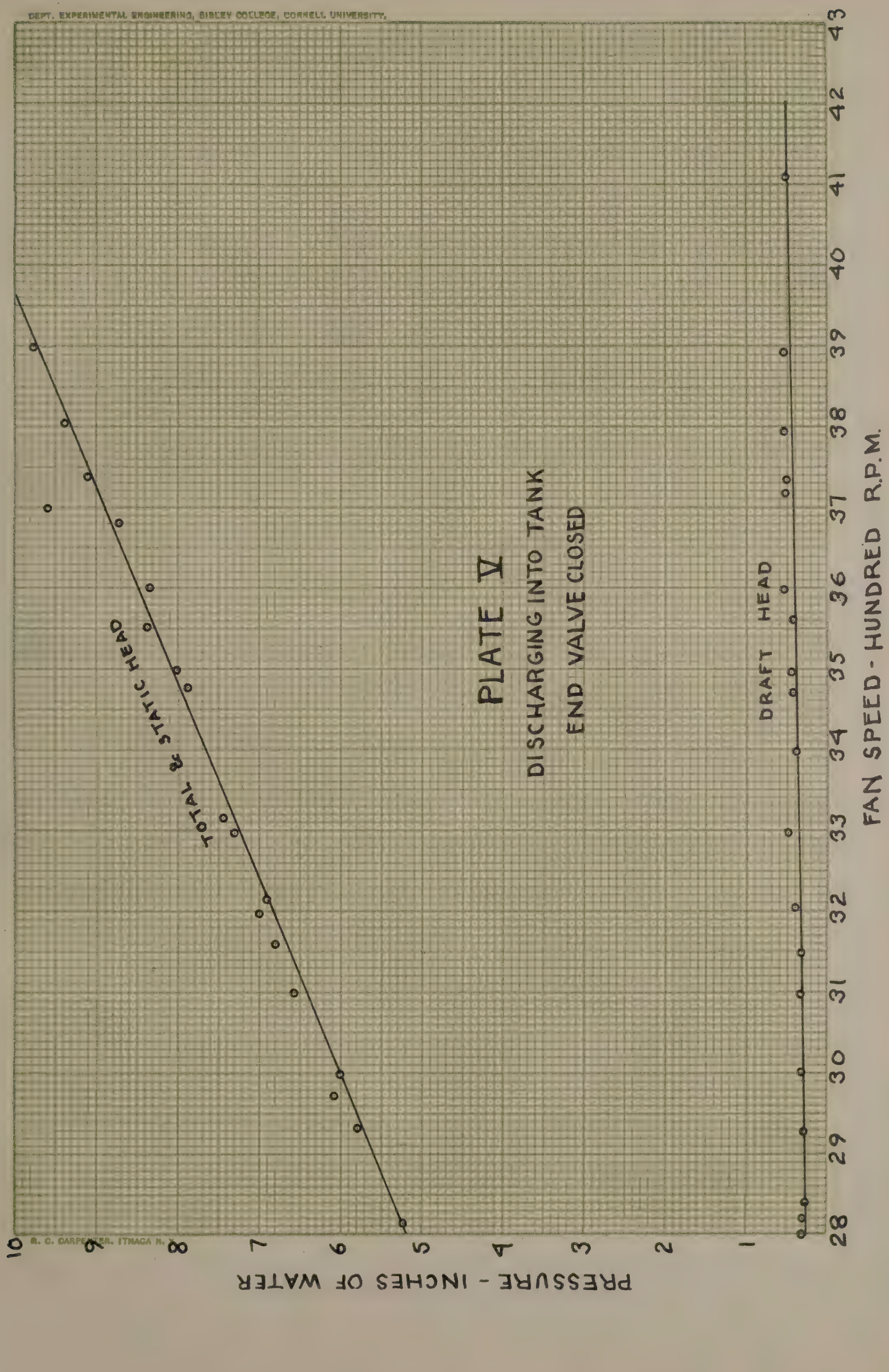
B. C. CARPENTER, ITHACA N. Y.
PLATE IV
DISCHARGING INTO TANK
END VALVE OPEN
TOTAL HEAD
STATIC HEAD
VELOCITY HEAD
DRAFT HEAD
FAN SPEED-HUNDRED R.P.M.
PRESSURE - INCHES OF WATER
25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
10 9 8 7 6 5 4 3 2 1



DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.
PLATE VI
DISCHARGING INTO TANK
END VALVE CLOSED
TOTAL & STATIC HEAD
DRAFT HEAD
FAN SPEED - HUNDRED R.P.M.
PRESSURE - INCHES OF WATER
28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43
1 2 3 4 5 6 7 8 9 10

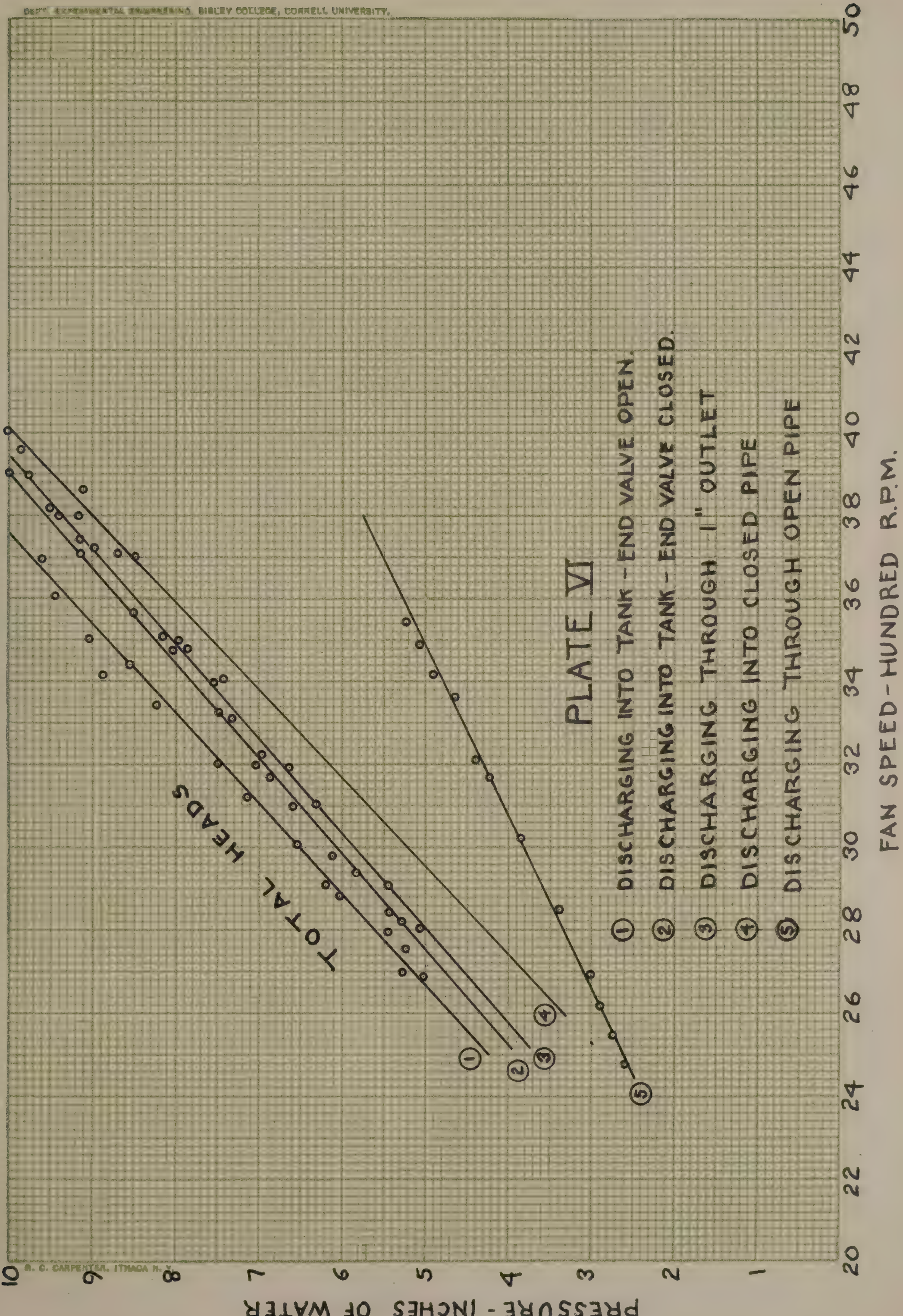

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PLATE VI
① DISCHARGING INTO TANK - END VALVE OPEN.
② DISCHARGING INTO TANK - END VALVE CLOSED.
③ DISCHARGING THROUGH 1" OUTLET
④ DISCHARGING INTO CLOSED PIPE
⑤ DISCHARGING THROUGH OPEN PIPE
TOTAL HEADS
FAN SPEED - HUNDRED R.P.M.
PRESSURE - INCHES OF WATER
20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50
1 2 3 4 5 6 7 8 9 10

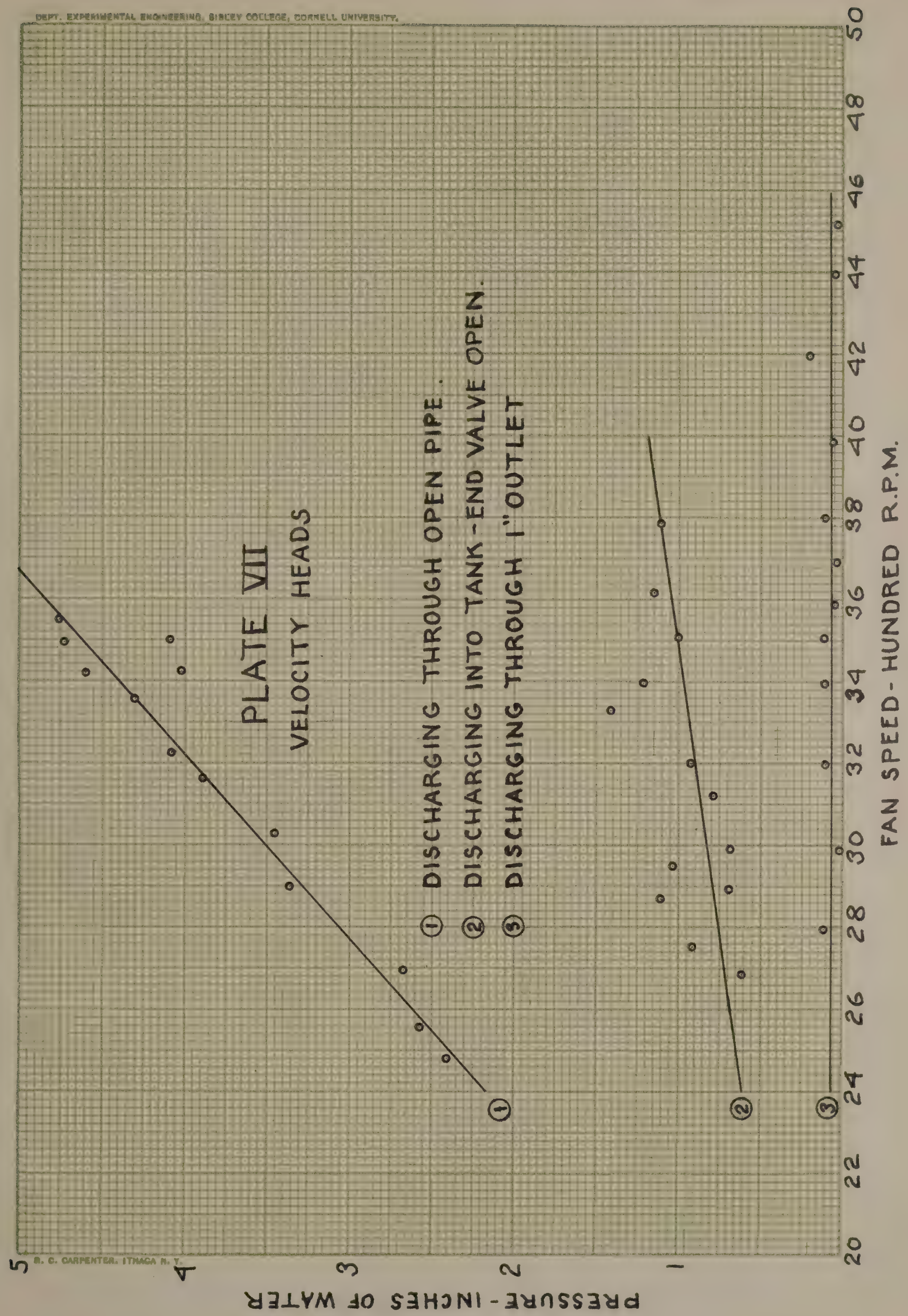
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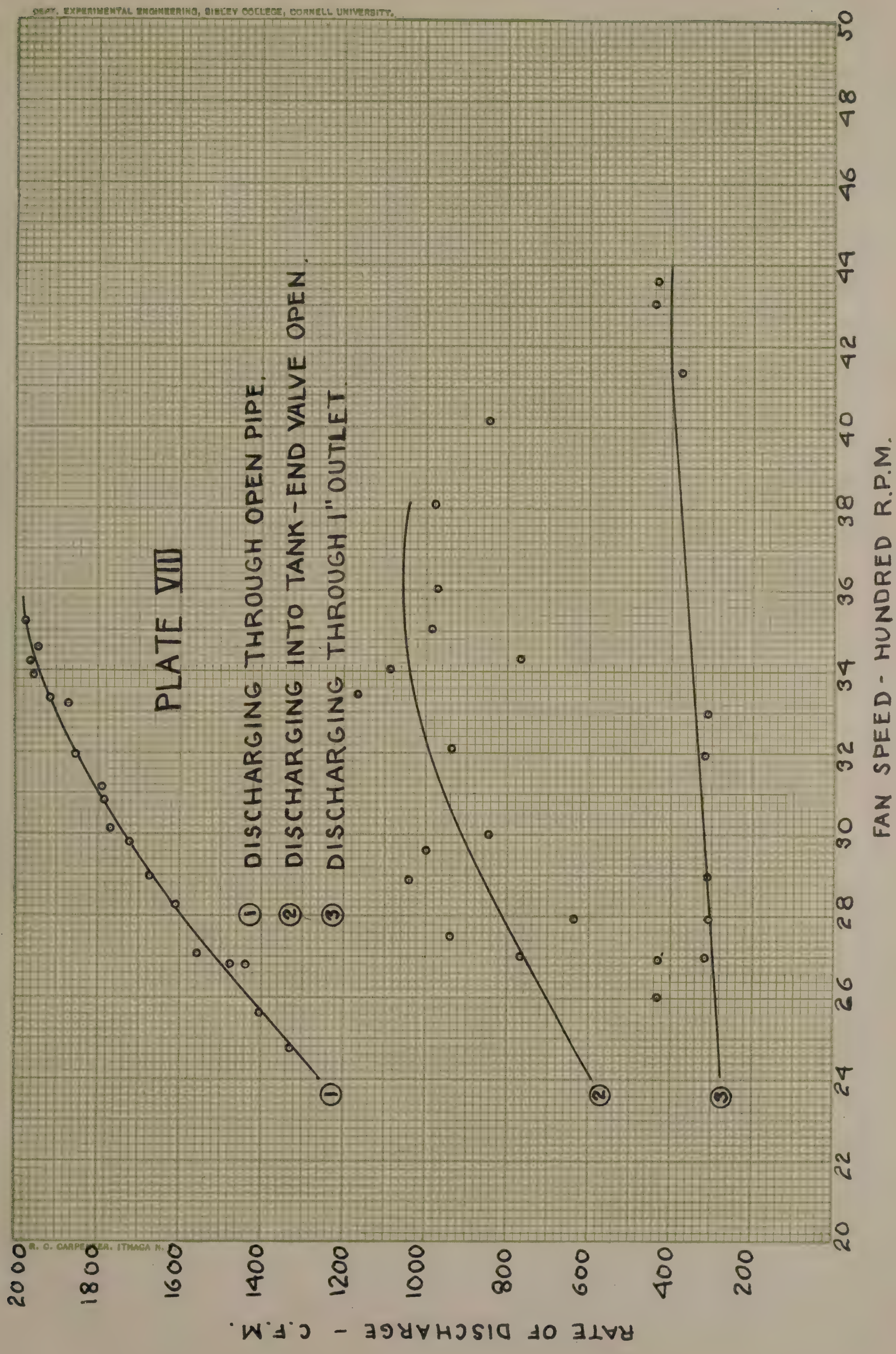
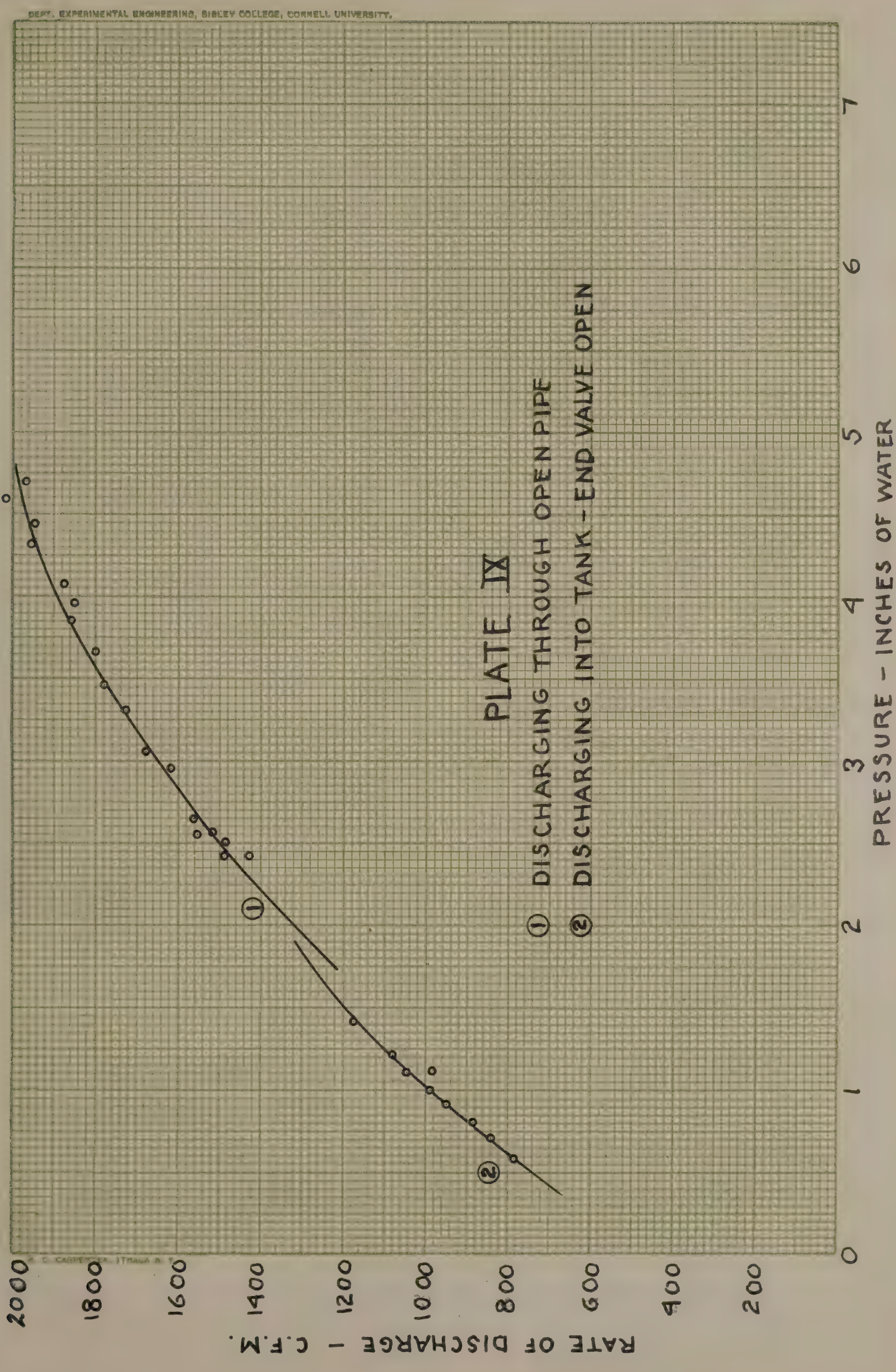
PLATE VII
VELOCITY HEADS
① DISCHARGING THROUGH OPEN PIPE.
② DISCHARGING INTO TANK-END VALVE OPEN.
③ DISCHARGING THROUGH 1" OUTLET
FAN SPEED-HUNDRED R.P.M.
PRESSURE - INCHES OF WATER
R. C. CARPENTER, ITHACA N. Y.


DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.
PLATE VIII
① DISCHARGING THROUGH OPEN PIPE.
② DISCHARGING INTO TANK - END VALVE OPEN.
③ DISCHARGING THROUGH 1" OUTLET.
①
②
③
2000
1800
1600
1400
1200
1000
800
600
400
200
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
RATE OF DISCHARGE - C.F.M.
FAN SPEED - HUNDRED R.P.M.


DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.
PLATE IX
① DISCHARGING THROUGH OPEN PIPE
② DISCHARGING INTO TANK - END VALVE OPEN
PRESSURE - INCHES OF WATER
RATE OF DISCHARGE - C.F.M.
0
1
2
3
4
5
6
7
200
400
600
800
1000
1200
1400
1600
1800
2000

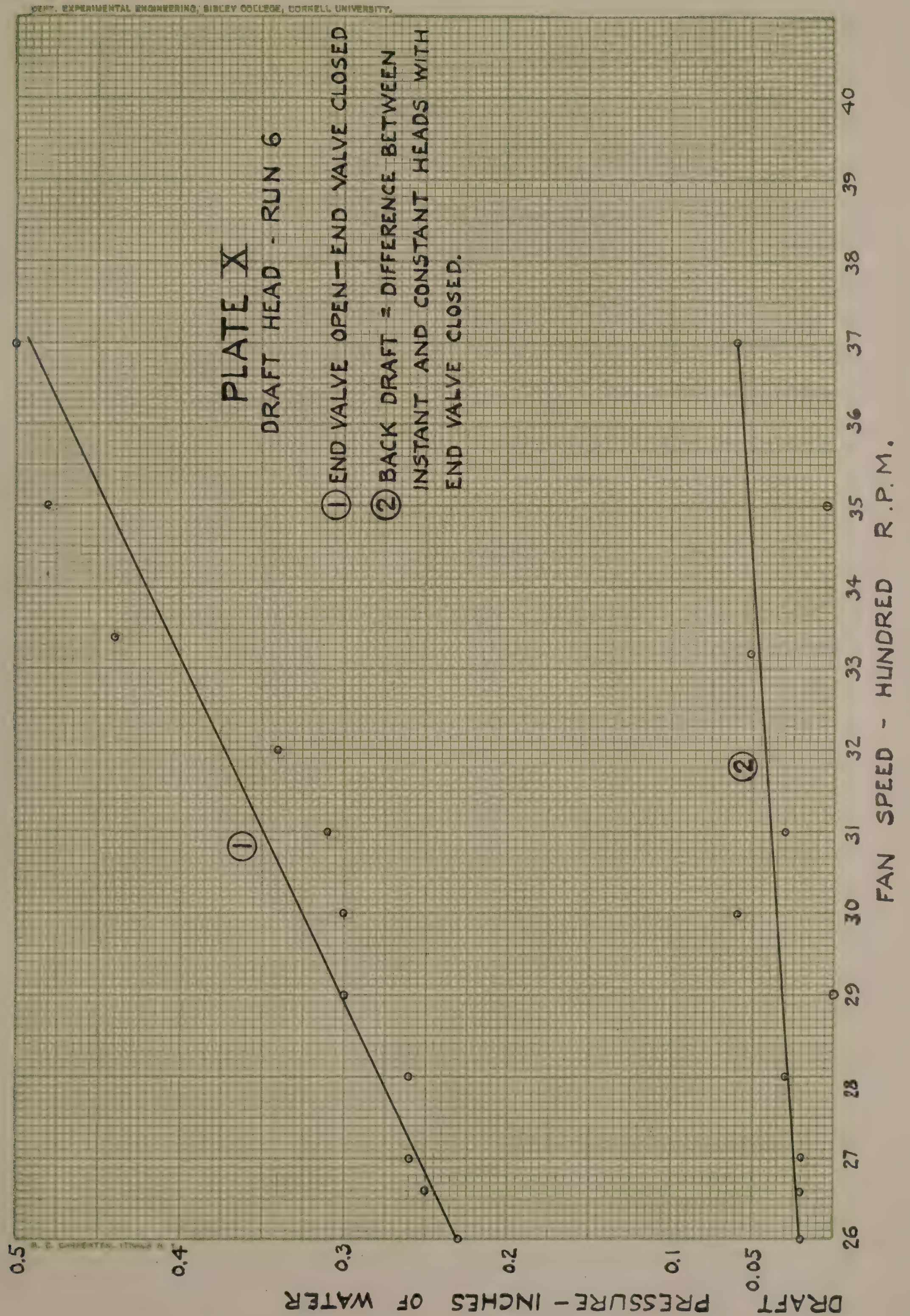

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PLATE X
DRAFT HEAD - RUN 6
(1) END VALVE OPEN—END VALVE CLOSED
(2) BACK DRAFT = DIFFERENCE BETWEEN INSTANT AND CONSTANT HEADS WITH END VALVE CLOSED.
(1)
(2)
DRAFT PRESSURE – INCHES OF WATER
0.5
0.4
0.3
0.2
0.1
0.05
FAN SPEED - HUNDRED R.P.M.
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40

DIAGRAM OF BLOWER

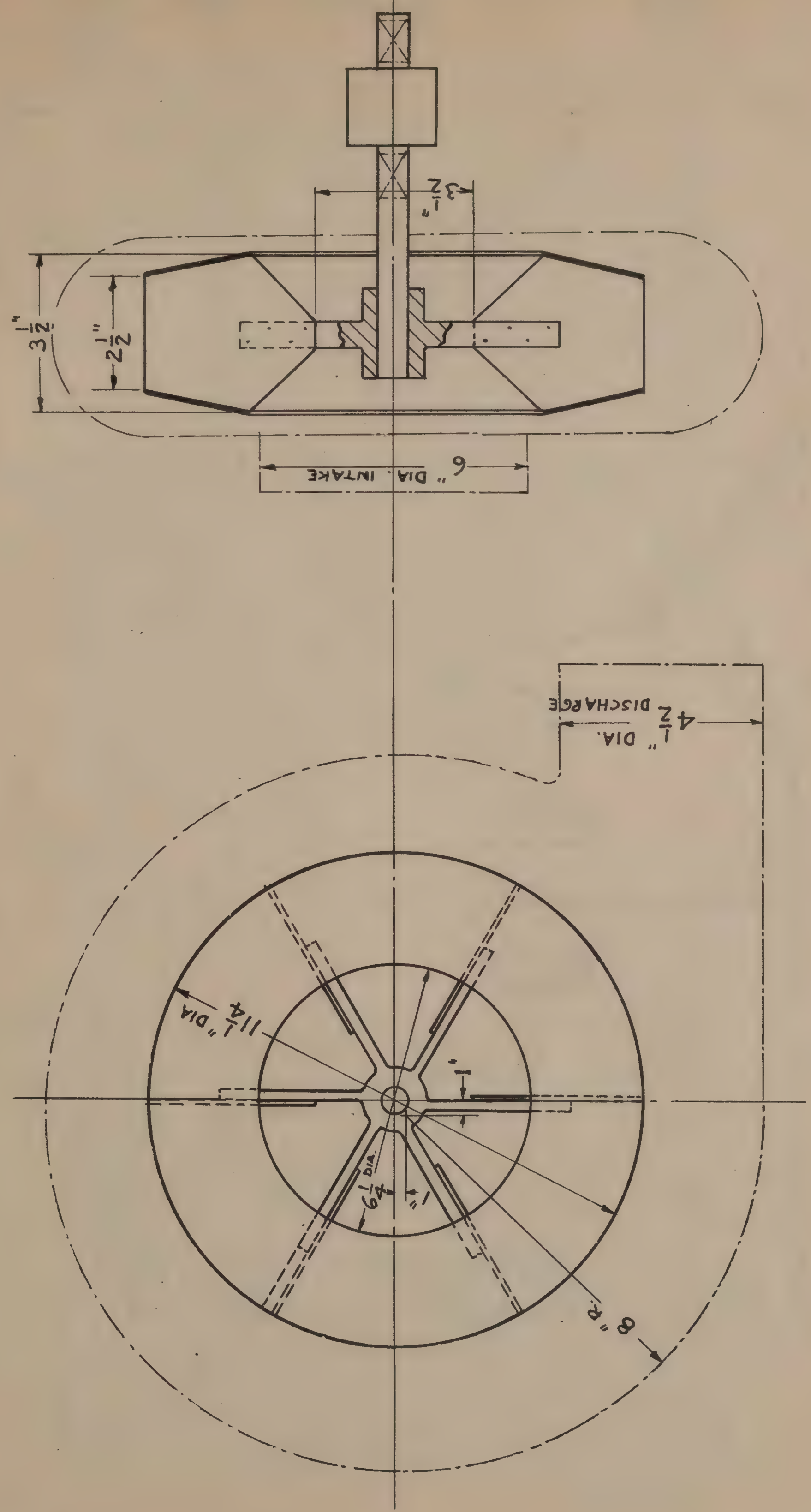


FIG. 1

DIAGRAM OF APPARATUS

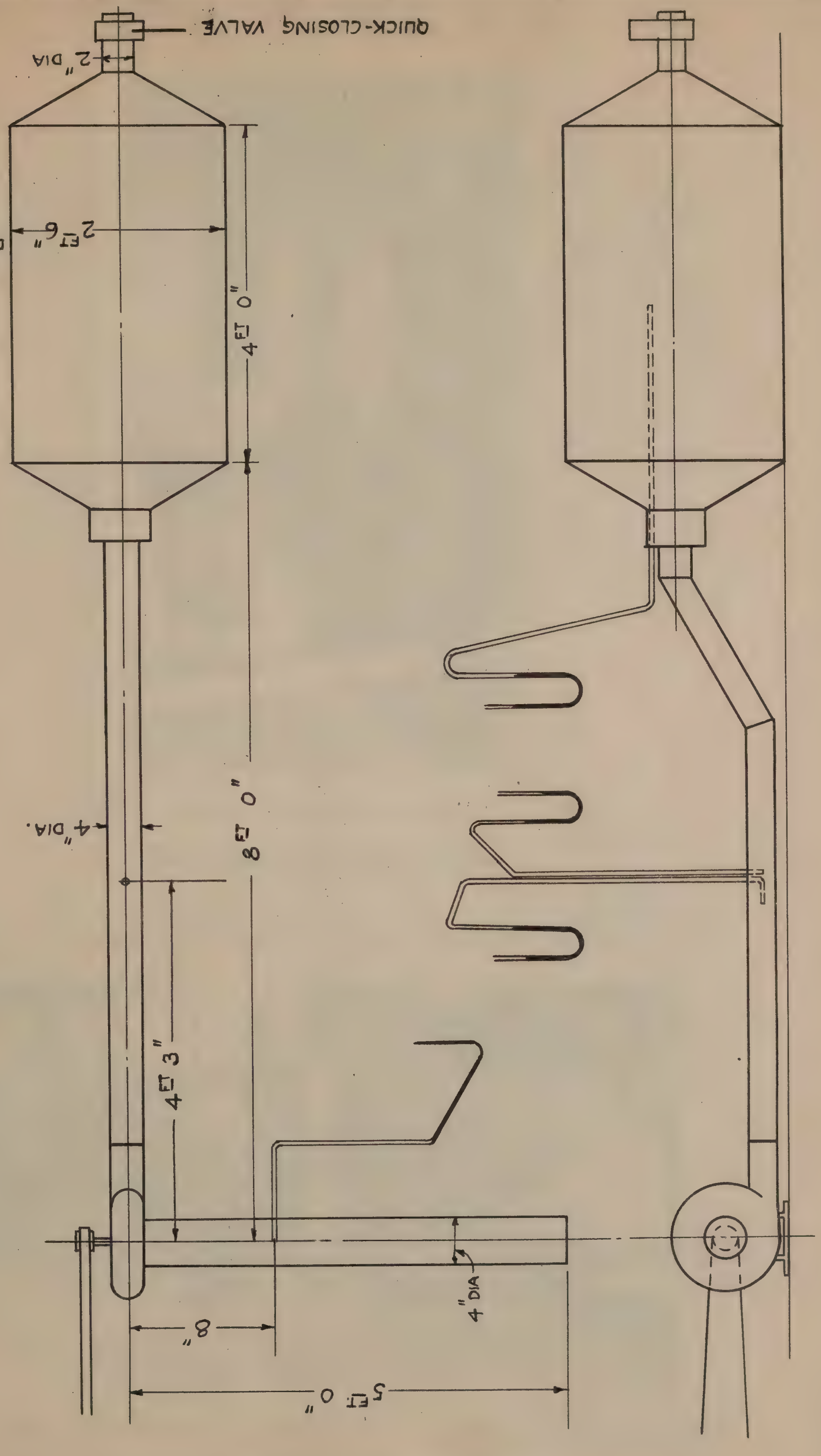
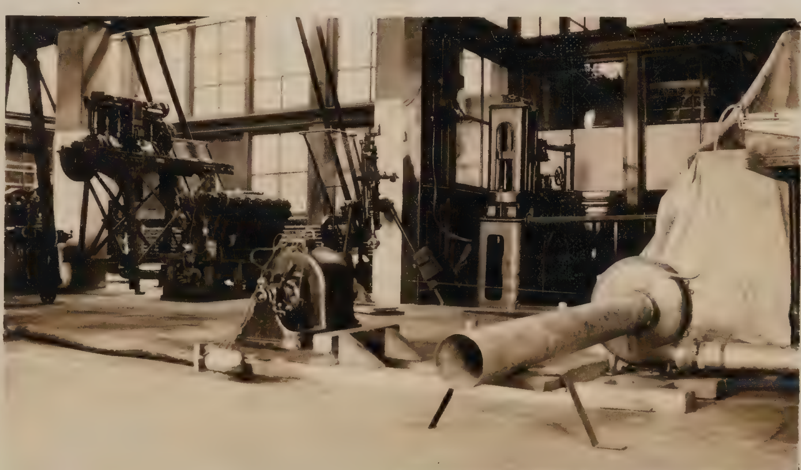


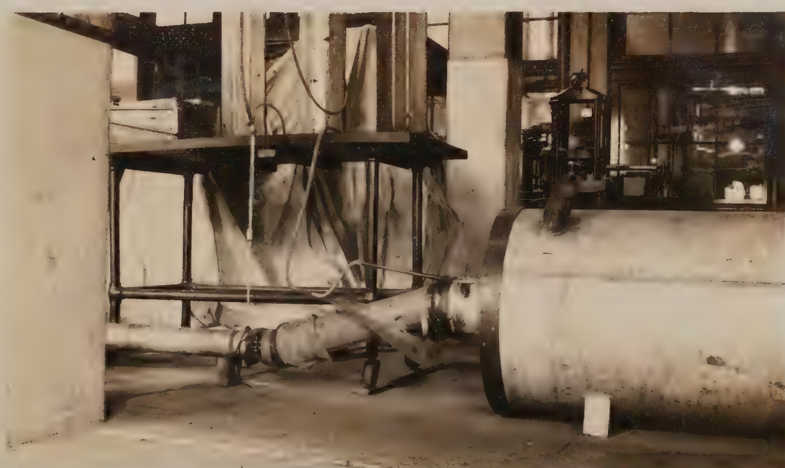
FIG. 2

Draft Gauge And Manometers.



General View Of Blower And Motor.

Quick-Acting Valve On End Of Tank.



Connection Between Discharge Pipe And Tank.

APPENDIX.

PRELIMINARY CURVES.

PLATES XI TO XVI

SUMMARY OF RUNS

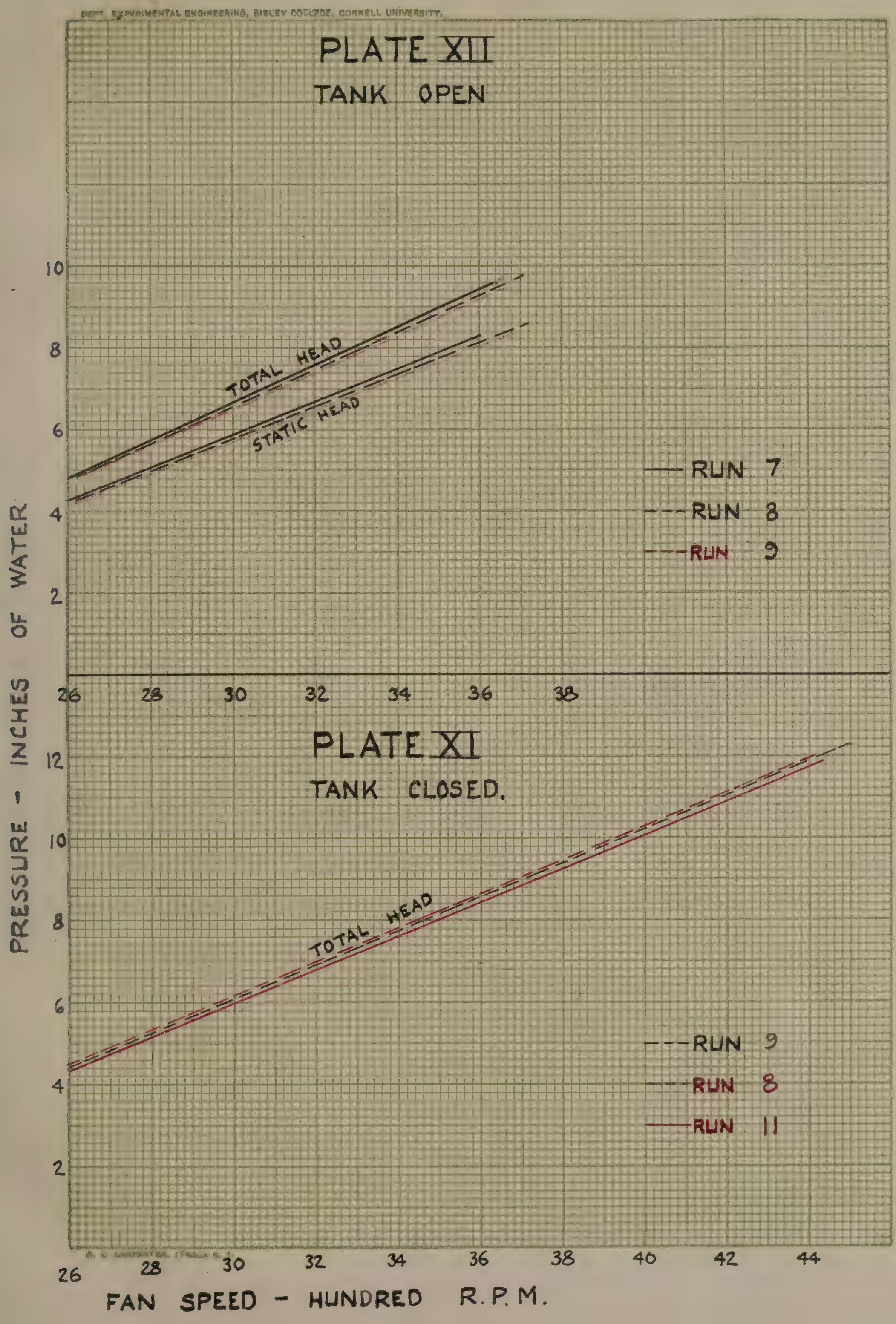
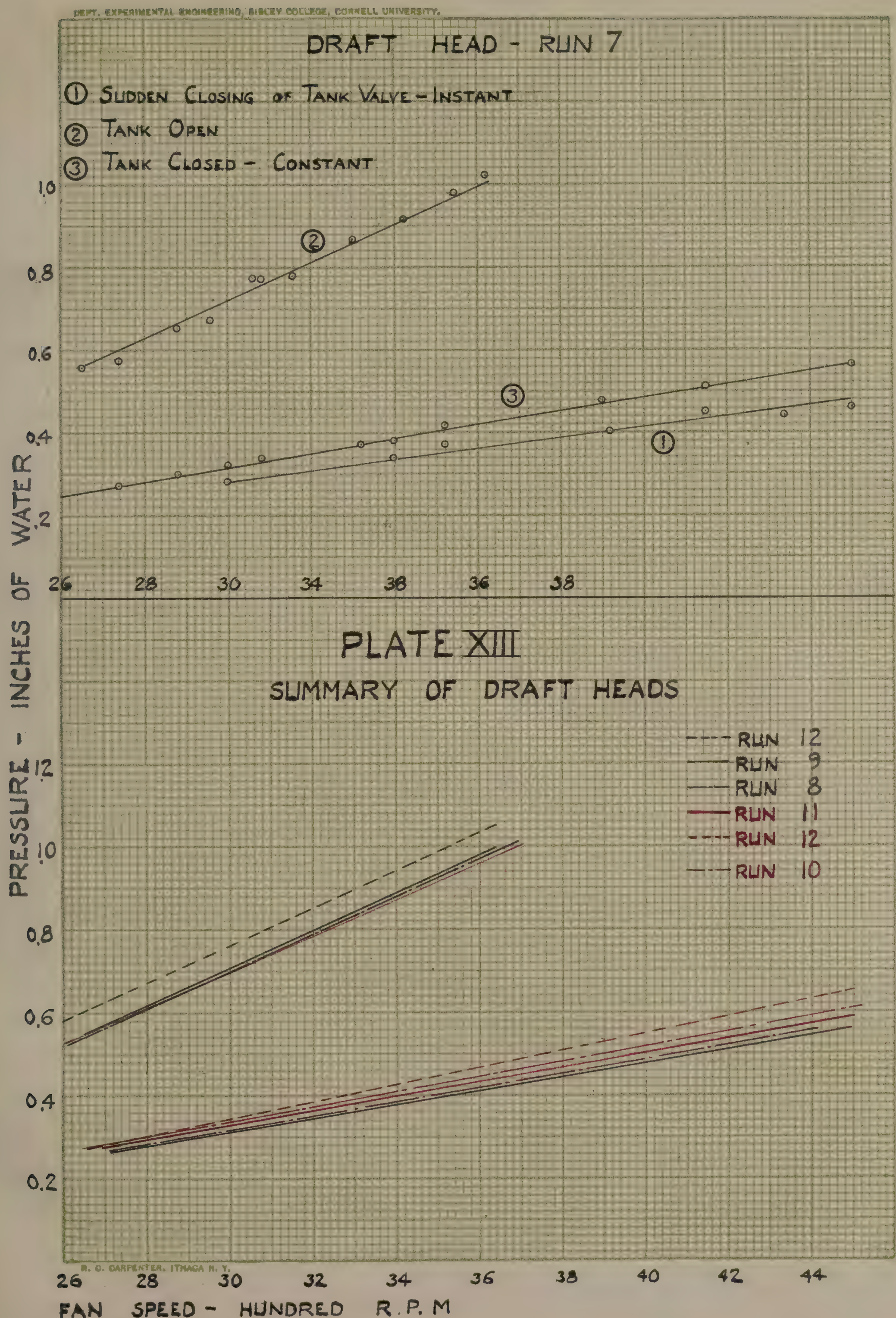


PLATE XIV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DRAFT HEAD - RUN 7
① SUDDEN CLOSING OF TANK VALVE - INSTANT
② TANK OPEN
③ TANK CLOSED - CONSTANT
PRESSURE - INCHES OF WATER
PLATE XIII
SUMMARY OF DRAFT HEADS
RUN 12
RUN 9
RUN 8
RUN 11
RUN 12
RUN 10
R. C. CARPENTER, ITHACA N. Y.
FAN SPEED - HUNDRED R.P.M

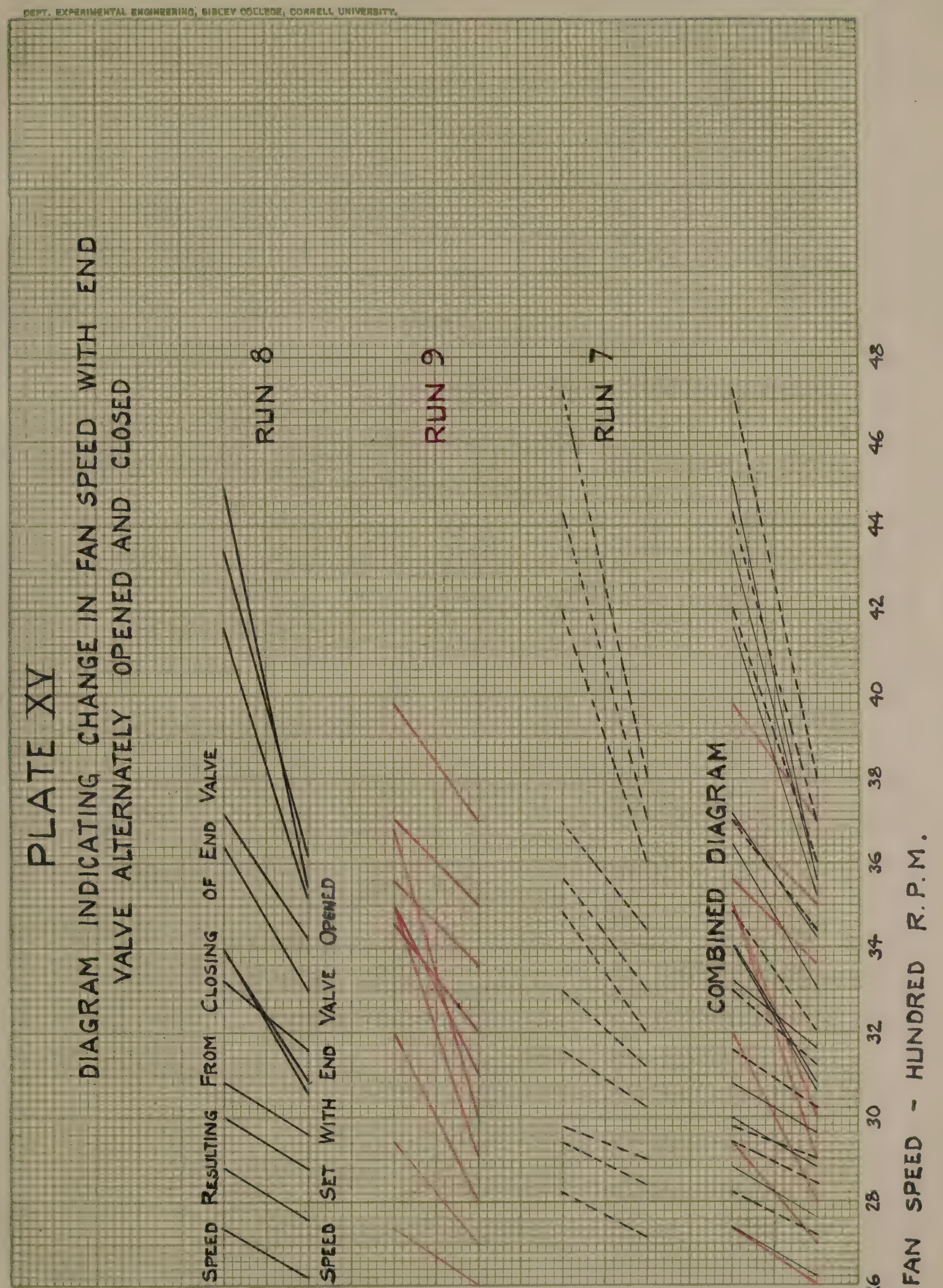
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PLATE XV
DIAGRAM INDICATING CHANGE IN FAN SPEED WITH END VALVE ALTERNATELY OPENED AND CLOSED
SPEED RESULTING FROM CLOSING OF END VALVE
SPEED SET WITH END VALVE OPENED
RUN 8
RUN 9
RUN 7
COMBINED DIAGRAM
26
28
30
32
34
36
38
40
42
44
46
48
FAN SPEED - HUNDRED R.P.M.
R. C. CARPENTER, ITHACA N. Y.

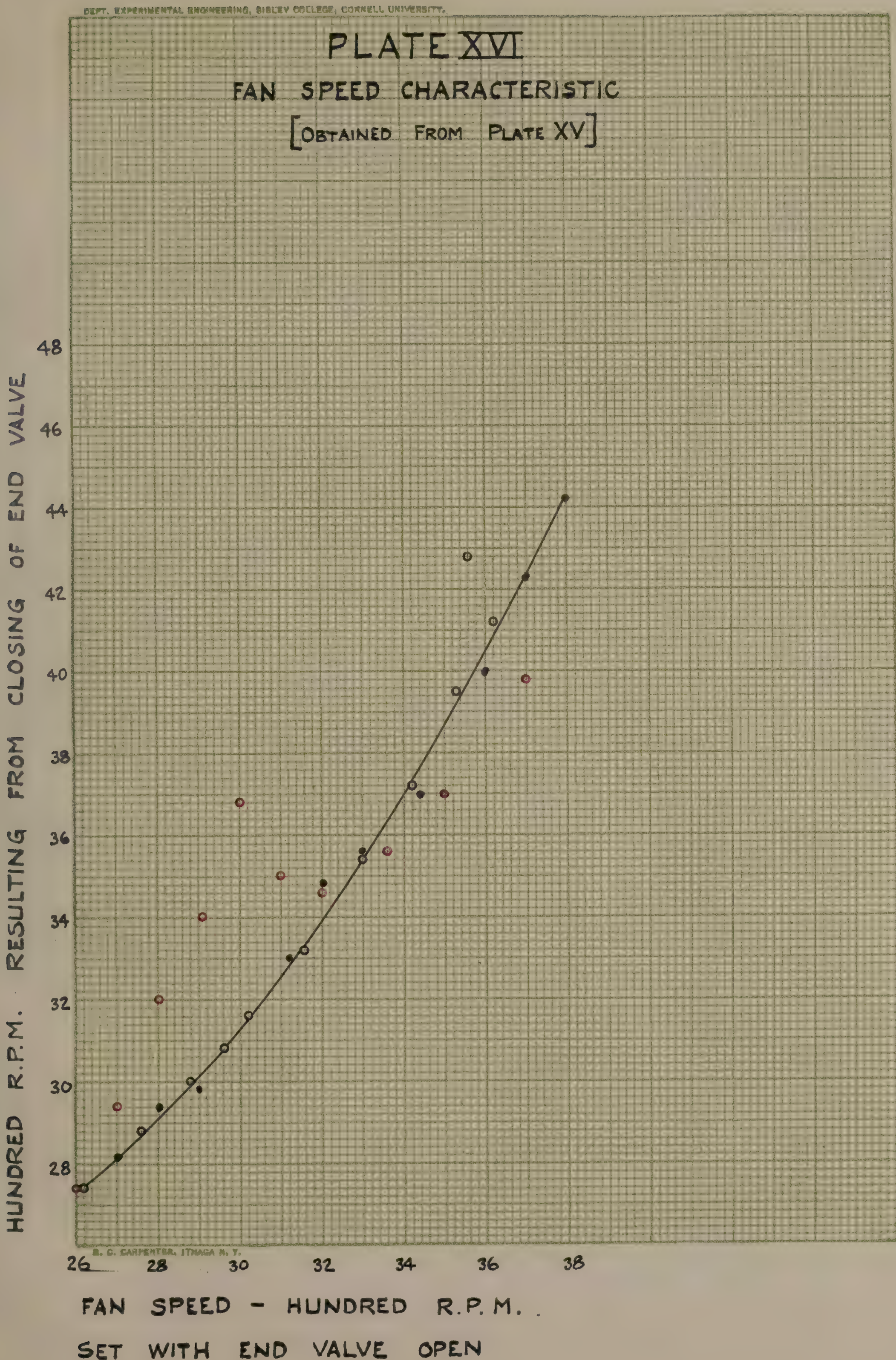
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PLATE XVI
FAN SPEED CHARACTERISTIC
[OBTAINED FROM PLATE XV]
HUNDRED R.P.M. RESULTING FROM CLOSING OF END VALVE
48
46
44
42
40
38
36
34
32
30
28
26
28
30
32
34
36
38
FAN SPEED - HUNDRED R.P.M.
SET WITH END VALVE OPEN

DERIVATION OF FORMULAE.

1. Discharge Velocity.

The pressure exerted by air in motion is

$$H = \frac{V^2}{2\,g} \qquad V^2 = 2g\,H \qquad (1)$$

where H = Pressure in feet of air

V = Velocity in Ft./Sec.

Applying this equation to the measurement of V by means of a Pitot Tube and water manometer:

$$V^2 = k\ 2g\ H\ \frac{D}{d}$$

where k = a constant = $\left(1 - 0.0257\ \frac{L}{D'}\right)$ (2)

L = 44" = Distance from mouth of fan to Pitot tube

D' = 4" = Dia. of discharge pipe

D = 62.3 = Density of water at 70 Deg.F

d = 0.0805 = " " air "

0.0257 = a constant, Sturtevant Co. Cat. #64

Substituting and converting V to Ft./Min. and H to "H_2O

$$V^2 = \left(1 - 0.0257 \times \frac{44''}{4''}\right) 64.4 \times \frac{62.3}{0.0825} \times \frac{1}{12} \times 3600 \times H$$

$$V = 11340\sqrt{H}$$

2. Rate of Discharge.

$$Q = A\,V$$

where $Q =$ Cu. Ft./Min.

$A =$ Area of discharge pipe in sq. ft.

$$Q = \frac{3.1416}{4} \times \left(\frac{4''}{12}\right)^2 \times V$$

$$Q = 0.0867\ V$$

RUN No. 1

DISCHARGING THROUGH OPEN PIPE.

Fan Speed R.P.M.	Total Head In. H_2O	Static Head In. H_2O	Velocity Head In. H_2O	Draft Head In. H_2O
3540	5.15	0.40	4.75	4.30
3500	5.05	0.35	4.70	4.15
3460	5.00	0.30	4.70	4.00
3400	4.80	0.35	4.45	3.95
3320	4.65	0.35	4.30	3.80
3200	4.30	0.35	3.95	3.50
3120	4.10	0.35	3.75	3.30
3020	3.80	0.35	3.45	3.25
2900	3.70	0.35	3.35	2.90
2820	3.30	0.35	2.95	2.70
2700	3.00	0.35	2.65	2.50
2660	3.00	0.35	2.65	2.45
2560	2.80	0.25	2.55	2.30
2520	2.60	0.25	2.35	2.15
2480	2.60	0.20	2.40	2.10

RUN NO. 2

DISCHARGING THROUGH PARTIALLY STOPPED PIPE
1" DIA. ORIFICE

Fan Speed R.P.M.	Total Head In. H_2O	Static Head In. H_2O	Velocity Head In. H_2O	Draft Head In. H_2O
2800	5.10	5.00	0.10	0.35
2900	5.50	5.40	0.10	0.35
3000	6.00	6.00	0.00	0.35
3100	6.25	6.25	0.00	0.35
3200	6.60	6.50	0.10	0.35
3500	8.10	8.00	0.10	0.40
3600	8.70	8.70	0.00	0.40
3700	9.10	9.10	0.00	0.40
4088	10.60	10.60	0.00	0.50
4152	11.00	10.80	0.20	0.55
4392	12.40	12.40	0.00	0.60

RUN NO. 3

DISCHARGING INTO CLOSED PIPE.

Fan Speed R.P.M.	Total and Static Heads In. H_2O	Draft Head In. H_2O
3700	8.70	0.50
3700	8.50	0.50
3780	9.10	0.50
3800	9.20	0.50
3880	9.55	0.50
3960	9.90	0.55
4000	10.10	0.60
4134	10.10	0.60
4180	10.90	0.60
4300	11.20	0.60
4318	11.35	0.60
4407	12.20	0.65
4432	11.70	0.65
4462	11.60	0.65

RUN No. 4

DISCHARGING INTO TANK - END VALVE OPEN.

Fan Speed R.P.M.	Total Head In. H_2O	Static Head In. H_2O	Velocity Hd. In H_2O	Draft Head In H_2O
2600	4.40	4.20	0.20	0.40
2700	5.40	4.80	0.60	0.70
2760	5.40	4.50	0.90	0.52
2800	5.40	5.00	0.40	0.54
2880	6.00	4.90	1.10	0.58
2900	6.20	5.50	0.70	0.85
2960	6.10	5.10	1.00	0.60
3000	6.50	5.80	0.70	0.86
3120	7.10	6.30	0.80	0,77
3200	7.50	6.60	0.90	0.98
3340	8.20	6.80	1.40	0.75
3400	8.80	7.60	1.20	1.12
3440	8.50	7.90	0.60	0.85
3500	9.00	8.00	1.00	1.10
3600	9.40	8.30	1.10	1.12
3800	10.90	9.80	1.10	1.13

RUN No. 5

DISCHARGING INTO TANK - END VALVE CLOSED.

Fan Speed R.P.M.	Total & Static Hd. In. H_2O	Draft Head In. H_2O
2800	5.20	0.30
2820	5.20	0.33
2940	5.80	0.33
2980	6.10	0.37
3000	6.00	0.30
3100	6.60	0.38
3160	6.80	0.42
3200	7.00	0.42
3220	6.90	0.36
3320	7.30	0.44
3400	7.40	0.42
3480	7.90	0.38
3500	8.00	0.45
3560	8.40	0.48
3600	8.30	0.47
3680	8.70	0.49
3740	9.10	0.51
3800	9.40	0.52
3900	9.80	0.53
4110	10.00	0.53

RUN No. 6

DISCHARGING INTO TANK -

END VALVE ALTERNATELY OPENED AND CLOSED.

FAN SPEED	DRAFT HEAD				
	Tank Open	Tank Closed		Back Draft	
		Constant	Instant		
	(1)	(2)	(3)	(2)-(3)	(1)-(2)
2600	0.51	0.28	0.26	0.02	0.23
2660	0.54	0.29	0.27	0.02	0.25
2700	0.56	0.30	0.28	0.02	0.26
2800	0.60	0.34	0.31	0.03	0.26
2900	0.64	0.34	0.34	0.00	0.30
3000	0.70	0.40	0.34	0.06	0.30
3100	0.72	0.41	0.38	0.03	0.31
3200	0.76	0.42	0.37	0.05	0.34
3240	0.88	0.44	0.41	0.05	0.44
3500	0.92	0.45	0.47	0.02	0.48
3700	1.00	0.49	0.45	0.06	0.51

RUN NO. 7

DISCHARGEING INTO TANK
END VALVE ALTERNATELY OPENED AND CLOSED.

	Fan Speed R.P.M.	Total Head In. H O	Static Head In. H O	Velocity Head In. H O	Draft Head In. H O
Open	2720	5.40	4.80	0.60	0.57
Closed	2820	5.20	5.20	0.00	0.33
Open	2840	5.80	5.20	0.60	0.60
Closed	2940	5.80	5.80	0.00	0.35
Open	2900	6.20	5.50	0.70	0.65
Closed	2980	6.10	6.10	0.00	0.37
Open	3020	6.60	5.80	0.80	0.71
Closed	3160	6.80	6.80	0.00	0.42
Open	3120	7.10	6.30	0.80	0.77
Closed	3320	7.40	7.40	0.00	0.42
Open	3200	6.70	7.50	1.20	0.76
Closed	3480	7.90	7.90	0.00	0.45
Open	3300	7.80	7.10	0.70	0.80
Closed	3560	8.40	8.40	0.00	0.47
Open	3400	8.40	7.50	0.90	0.86
Closed	3440	7.90	7.90	0.00	0.43
Open	3440	8.50	7.90	0.60	0.85
Closed	3700	9.60	9.60	0.00	0.53
Open	3600	9.60	8.60	1.00	1.03
Closed	4210	12.80	12.80	0.00	0.73
Open	3700	9.80	8.70	1.10	1.08
Closed	4430	13.40	13.40	0.00	0.73
Open	3800	11.00	9.80	1.20	1.13
Closed	4740	15.00	15.00	0.00	0.86

RUN No. 8

DISCHARGING INTO TANK -

END VALVE ALTERNATELY OPENED AND CLOSED.

Repetition of RUN No. 7

RUN No. 9

DISCHARGING INTO TANK -

END VALVE ALTERNATELY OPENED AND CLOSED.

Repetition of RUN No. 7

RUN No. 10

DISCHARGING INTO TANK - END VALVE CLOSED.

Repetition of RUN No. 5

RUN No. 11

DISCHARGING INTO TANK - END VALVE CLOSED.

Repetition of RUN No, 5

RUN No. 12

DISCHARGING INTO TANK - END VALVE OPEN.

Repetition of RUN No. 4

CALCULATED RESULTS.

RUN No.1

Fan Speed R.P.M.	Discharge Vel. Ft./Min.	Quantity Discharged Cu.Ft./Min.
3540	24700	2130
3500	24400	2110
3460	22600	1960
3400	22500	1950
3320	22000	1905
3200	21200	1840
3120	20600	1785
3020	20400	1765
2900	19300	1670
2800	18600	1608
2700	17900	1550
2660	17600	1520
2560	17100	1480
2520	17100	1480
2480	16350	1415

CALCULATED RESULTS - RUN No.2

Fan Speed R.P.M.	Discharge Vel. Ft./Min.	Quantity Discharged Cu. Ft./Min.
2800	3590	310
2900	3590	310
3200	3590	310
3500	3590	310
3800	3590	310
4138	4300	372
4152	5080	437
4202	5080	437

RUN No.4

2600	5070	439
2700	8780	760
2760	10750	930
2880	11900	1032
2900	9480	822
2960	10340	984
3000	9480	821
3120	10300	879
3200	10750	930
3340	13410	1161
3400	12410	1075
3500	11350	983
3600	11900	966
3800	11900	966

SUGGESTIONS FOR FUTURE INVESTIGATIONS.

While this investigation has shown that in the case of the particular apparatus used, the back draft effect may be ignored, there is a possibility that, were the discharge pipe of the blower shorter or of smaller diameter, the compression wave might be transmitted without undergoing any appreciable absorbtion, and produce an actual drop in pressure in the tank. It is therefore suggested that a series of runs be made using different sizes of discharge pipes, to determine if such is actually the case, and if so, between what range of pipe sizes the back draft may be neglected.

It would be interesting furthermore to increase the speed of the fan to the greatest that might be safely attained and find out if the characteristic curves of this type of fan commence to droop or break; within the rated speed range, the pressure curves are all straight lines.

It would be better to connect the manometers differentially in future, so that all heads could be read directly, instead of taking only total and static heads and subtracting to find the velocity head, as did the present writers.